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LANDING IMPACT CHARACTERISTICS FROM MODEL TESTS

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SUMMARY

The great importance of hull strength in flying boats to withstand adverse operating conditions has been amply demonstrated and emphasized by recent military actions. It has been evident for some time that the present design specifications for bottom loading do not have a very exact or sound basis; and there has been a revival of effort to obtain the necessary data, at the new impact basin of the NACA Langley laboratory (controlled model tests) and in industry by a close review of full-scale experience.

While these programs are good, they will not be completed in the near future. Thus, in order to provide preflight information on the probable water loads on the JRM-1 during rough water landings, a program of dynamic tests was undertaken at the Stevens Institute of Technology on the 1/30-scale model. The program consisted of landings in various wave sizes at several trim angles and forward speeds with controlled sinking speed at contact. Data were obtained from new apparatus and acceleration recorder which made possible simple, rugged test technique yielding immediately available records of accelerations at bow and center of gravity and the resulting trim path during and after impact.

The impact acceleration and trim data are analyzed to show the trend of accelerations (both linear and angular) with wave size and length-height ratio. It is indicated that design accelerations for the flying boat will be closely approached but not exceeded in the specified rough water. Best landings (from a trimming standpoint) will be obtained with approach trims near 4° or 5° (base line).

INTRODUCTION

The operation of flying boats under the trying conditions of advanced combat zones in all kinds of weather has demonstrated the prime importance of seaworthiness and bottom strength in such craft. There have been numerous instances in which these flying boats have been operated from the open sea with no nearby land base. Even minor straining or breaking of the hull bottom on landing (or other service) might result in loss of the flying boat due to excessive leakage since there would be very little chance of repair on the water. In either rescue or combat work little can be done to avoid rough water. The flying boat that can take it will be the design used.

This recent rough usage has helped the revival of effort to obtain the necessary data for sound hull bottom design. Gaps and inconsistencies in the present general specification requirements appear in each actual design case. At the Glenn L. Martin Company an effort has been made to carry the design requirements across the specification gaps without excessive weight penalty (with good success, judging from PBM-3 performance). Other organizations, as well, are making renewed efforts to correlate available full scale data for future design work. At the new impact basin of the NACA Langley laboratory tests of models under controlled conditions have been started (reference 1). Extension of the theoretical approach to the impact problem (begun in reference 2) is being carried along with the experimental work by the impact-basin staff to some extent.

Although these programs are headed in the right direction, it seemed evident that they would be continued for some time before any generally applicable data would issue forth to solve specific design problems. Thus, to investigate specific designs, a more direct and immediate method of dynamic model tests was developed for use at the Experimental Towing Tank, Stevens Institute of Technology.

This report deals with the test technique and results obtained for the landing characteristics of the 1/30-scale JRM-1 model in smooth and rough water. The impact loads on this flying boat are particularly of interest because a rough water landing requirement has been added to the detailed specification since the design and construction of the "Mars" prototype.

DESCRIPTION OF MODEL AND APPARATUS

The model and the apparatus are shown in figure 1 and more fully described in the tank report (reference 3), but a few points require special note since they affect the application of the test data to the full-scale flying boat.

With reference to the correspondence of the model with full scale:

Mass, pitch inertia, aerodynamic moment and damping, forward speed, sinking speed, and wave size were maintained dynamically similar.

Model restraint in roll and yaw would have no effect on the symmetrical impacts tested.

Horizontal deceleration, structural elasticity, and true wing lift were not represented in the model.

The accelerometer units were developed during preliminary tests beginning April 1944 to meet the unique requirements of the tank work: to obtain immediately available records of a great number of runs with a minimum of equipment and manpower. For this reason the simplest form of cantilever beam accelerometer with extended pointer (for magnification) was used recording directly on a moving smoked glass slide. Balance of the probable instrument response fidelity against the accuracy of measurement of the records from the slides resulted in choice of the lowest possible frequency (30 cps) with approximately 0.6 critical damping. This instrument natural frequency compares closely with that used at the National Advisory Committee for Aeronautics (reference 1).

Since the accuracy of the accelerometer used at the Stevens Institute of Technology would depend upon its response to isolated blows of varying intensity and rate of application, no formal calibration was made at various frequencies. Instead, it was assumed in interpreting the data that the static response would be linear within the required deflection range, and that the theoretical response correction for various frequencies (at 0.6 critical damping) would not be applied. This was done not only to save work, but was actually necessitated by the impossibility of knowing the effective impressed frequency without previous detailed knowledge of the rate of load application.

To establish this procedure as a reasonable one, a dummy test was made with standard GLM pickups mounted directly beneath the S.I.T. accelerometers. This double setup was subjected to a number of single impact tests to obtain simultaneous records from the two sets of instruments. The data are plotted in figure 2 for all cases in which the natural frequency of the GLM pickup circuit was not excited (100 cps). It is evident that reasonably accurate response can be expected from the simple accelerometers used at the tank.

Unfortunately, weight and inertia limitations set by the model dynamic similarity requirements prevented the use of a larger spacing between the bow and center-of-gravity accelerometers. Since the angular acceleration is obtained from the difference between bow and center-of-gravity linear acceleration divided by the spacing, the accuracy at low angular accelerations is not good (small differences between large numbers). However, at higher angular accelerations the probable accuracy is considerably improved.

Rather than complicate the model and increase the minimum weight by adding a wing to the normal bare hull, a long torsion spring of low spring rate was used for an unloader. This had the added feature obtaining the required sinking speed in a reasonable dropping distance by a latch arrangement which allowed a period of free fall before application of the unloading force.

The minimum landing weight that could be obtained on the model corresponds to 175,000 pounds full scale. This is not serious because the accelerations do not have a large variation with impact mass for a given shape. (See reference 1.)

RANGE OF INVESTIGATION

The specific object of this investigation was the determination of the maximum acceleration and trimming characteristics of the JRM-1 when landing in rough water. In order to provide a wide coverage of wave sizes and landing positions, most of the tests were made at one forward speed and one sinking speed. The sinking speed chosen (approx. 13 fps full scale) is a reasonable maximum which might obtain from a steep glide path or stall condition (either from pilot error or bounce from previous contact). The forward speed (89 mph) was not varied with trim angle since that would depend upon glide path or previous wave contact as well as horizon trim. This speed approximates the water speed under moderate sea conditions (15 to 20 mph wind).

The unloading to represent wing lift was taken at 80 percent of the gross weight as a condition which might be obtained during landing (due to reduction in trim or bounce from previous waves). This introduces small variations in the actual model sinking speed at contact, but for comparison purposes the speed was calculated to the initial still water level.

Although flight tests of the JRM-1 probably will be conducted in Cheasapeake Bay, where the ratio of wave length to height may be as low as 10:1, the model tests were made at greater length ratios as well.

Subsidiary tests were made with various unloadings and at lower speeds to check the trends of maximum impact. Also a short investigation was made of the effect of center-of-gravity position and moment of inertia in the design wave size (3.5 ft).

A short separate study of the relative second step landing characteristics was made for the XPB2M-1, XPB2M-1R, and JRM-1 models in smooth water. Angular accelerations and trimming characteristics are compared for the three models, basically similar except for their afterbody design.

PRESENTATION AND DISCUSSION OF RESULTS

Peak Center-of-Gravity Accelerations

Since the position of contact of the hull bottom on the wave surface is a major factor in rough water impact, it was necessary to make a series of landings in different portions of the wave contour at every condition of speed and trim angle. For lack of some device accurately to time the model release with respect to the moving wave the position of contact was determined by chance, relying upon a large number of runs to cover the possible conditions. Fortunately, the variation of center-of-gravity acceleration with trim angle (0° to 6° base line) was small; because it later became apparent that the eight runs initially scheduled were not sufficient to guarantee coverage of the maximum possible accelerations.

Thus, in figure 3, the peak accelerations are plotted for each wave size and ratio irrespective of trim, which gives at least 16 runs in each wave. The lengths of the blocks in the plot are representative of the proportionate number of landings yielding that peak acceleration in steps of 0.5g. The actual range of measured accelerations is shown in each wave by the heavy vertical line joining the blocks. Note that at 3.75-foot wave size, where a greater number of runs were made (approx. 30), the frequency-of-occurrence blocks form a much smoother curve than elsewhere.

Inspection of the plot reveals several definite trends. Maximum peak accelerations increase practically linearly with wave height. The longer waves give greater maximum values. Average peak accelerations increase more slowly for small waves and then more rapidly above the 5.0-foot height. Up to the 5-foot height the length of wave has little effect on the average peak acceleration.

It was somewhat surprising at first to obtain occasional landings in waves (up to 5 ft high) which had lower accelerations than the smooth water landings. From motion pictures taken during preliminary tests it appeared that these very mild impacts occurred when the main step area contacted the waves quite near the crest and most of the descent energy was absorbed riding down the back side of the wave. When the first crest was just missed, entrance into the second wave was with full sinking speed and well down on the forward slope of the wave so that maximum impact resulted.

The ultimate load factor for the JRM-1 is given as 5.94 in a report by The Glenn L. Martin Company, 1945. Figure 3 shows that this never would be exceeded in 3.5-foot waves (for the assumed initial approach conditions) and would be reached only occasionally in 5-foot waves. Comparison of the design load factor $\frac{5.94}{1.35} = 4.4$ with the frequency-of-occurrences plot indicates that normal operation in 3.5-foot waves would exceed the yield loads rarely and in only the longer waves. In fact, the probability of not exceeding the yield loads is good even in 5-foot waves.

Since the initial conditions were set at maximum probable severity for impact loads, it is quite possible that landings in larger waves could be survived by careful pilot technique. It can be expected that rough water, full scale flight test will not normally yield as high accelerations as the model because the pilot will in most cases use his skill to obtain low sinking speeds.

In the normal operation of a flying boat of this type it can be expected that rough water will be avoided whenever practicable even though the hull strength is sufficient. The combination of severe landing conditions coupled with lack of pilot technique (forced landing during blind flying, for instance) would occur few times during the life of this flying boat. Such cases would be survived as long as the ultimate load factors were not exceeded.

PEAK BOW AND ANGULAR ACCELERATIONS

In figure 4 are plotted the peak angular accelerations obtained from the difference between bow and center-of-gravity accelerometer records. The bow accelerations, plotted in figure 5, have been corrected to the actual bow of the model by extrapolation from the center of gravity and bow accelerometer records. In both of these plots the same general trend of acceleration with wave size appears as for the center-of-gravity accelerations. However, the effect of wave length is more pronounced, and the spread of values at each wave size is much greater. Also, the variation of angular and bow accelerations with approach trim angle was sufficient to warrant plotting high and low trims separately. During a number of landings negative angular accelerations were obtained. The approximate maximum values of this negative angular acceleration are plotted in figure 4 without any attempt to indicate frequency of occurrence.

From the spread of the recorded data for each wave size it is apparent that the location of the impact area is most important. This is entirely logical since the angular acceleration is a measure of moment. The impacts well forward on the bottom may not yield as high center-of-gravity accelerations as more central blows, but the resulting moment during the early stages of the impact may be critical. This effect is further indicated by the tendency of peak angular accelerations to occur before peak center-of-gravity acceleration (in time). Thus, it is quite possible for the same wave to cause maximum peak angular and center-of-gravity accelerations, but not simultaneously.

A very noticeable characteristic of the plot of angular acceleration is the relative infrequency of occurrence of the maximum peak values. More than 30 runs were made with 0° trim in 3.75-foot waves and only once was 3 radians per second square exceeded; and, in that case, the value was almost 50 percent higher. From study of the superposition of the hull profile on a trochoidal wave form it seems possible that even that value could be exceeded by a perfect combination of most critical conditions. Since the rare occurrence of the maximum peak angular acceleration in model test probably would be as infrequent in full scale, it would be fitting to consider the ultimate load factor as an allowable limit to these extreme cases.

During impact at moderate to high angles in waves it often happens that the second step area receives a sizable load which results in negative moments. When the bow is relatively dry (or lightly loaded), the moment from the second step load causes a negative angular acceleration (plotted in fig. 4 as mentioned formerly). However, when bow and stern are subjected to simultaneous loads, the resultant angular acceleration is not a measure of the internal moments. This particular condition may arise most often in waves about one-half to three-fourths of the length of the hull. Although this would cause some trouble in the interpretation of the acceleration records, it is believed that the higher values of positive angular acceleration are truly representative of the bow loads (especially at low trims).

Yield design factors for JRM-1 bow landing as given in a report by The Glenn L. Martin Company in 1945 are 4 radians per second square plus 3g at the center of gravity. These factors were exceeded only once (0° trim 3.75- by 75-ft wave) in all the runs up to the 5-foot wave height. As pointed out above, the perfect combination of conditions might exceed these loads, but the possibility of their occurrence is slight. Since low trim angles could be avoided and the average of all landings yields quite low angular accelerations, there should be no difficulty encountered from this source on the flying boat.

TRIMMING CHARACTERISTICS

The variation of trim angle during and after impact was mainly a function of the approach or initial angle of contact. The magnitude and violence of the trim changes increased with the wave size, but in all waves the same characteristics were exhibited depending upon the contact trim.

At low trim angles (below 2° base line) the bow penetrated the first or second wave, and large positive angular acceleration occurred. In general, the trim rapidly increased to a maximum of 8° to 12°. At these high trims the afterbody soon made contact and reduced the trim to a low value. If the true wing lift (increasing with trim angle) had been applied, it is probable that many of the low trim approaches would have resulted in bouncing clear of the water at rather high trims. This is particularly dangerous after some flying speed has been lost, since stall and uncontrolled drop into the waves may result.

At approach angles above 6° base line the second step usually hit first, causing impact of the forebody in a decreasing trim attitude. At times, this resulted in high bow accelerations, but otherwise the trim path through the impact and subsequent waves was quite steady.

The best landings (from a trimming standpoint) were obtained at approach angles of 3° to 6° base line. The variation of the trim during impact and through the waves was often less than 3°, with the least variation at 5° approach angle (in 3.75 ft waves). Although a lower landing trim might be desirable in smooth water (due to the possibility of "skipping"), that type of instability could hardly exist in rough water. Thus, 5° base line trim is recommended as the best approach angle for rough water landing on the basis of trimming characteristics.

SECOND STEP LANDINGS

Limitation in the apparatus to the amount of total drop prevented complete study of the second step landing conditions. Drops in smooth water at trim angles from 8° to 14° resulted in a fairly constant negative angular acceleration of 1.55 radians per second square. Although the second step impact was completed, the apparatus hit the stops before completion of the main step impact; so no full story of the effect of the trimming motion (resulting from the negative angular acceleration) upon the main step loads could be obtained.

Similar tests in smooth water were made with the original XPB2M-1 afterbody (with chine flare) and XPB2M-1R afterbody (most of the afterbody flare removed) attached to the landing model. The trend of recorded negative angular accelerations listed below is the same as obtained in flight test of those two hulls although to a lesser extent.

	(rad/sec.^{2})
XPB2M-1	2.15
XPB2M-1R	1.80
JRM-1	1.55

At the test sinking speed the flying boat is stalled at a trim angle of approximately 6°. The conventional picture of a stalled approach at higher angles corresponds to a lower sinking speed. Apparatus limitations prevented the complete study of high angle approaches, but it is thought that the lower trim angles at high sinking speeds give similar afterbody impacts. The peak negative accelerations during regular drops were picked out, and maximum values were plotted approximately in figure 4. Here again these may not represent the full story, since the accelerometers record only the over-all external moment when actually bow and stern loads may be in external moment balance. Only theoretical analysis of the impact or determination of the loads from strain or bottom pressure gages will yield the complete load story.

THE EFFECT OF DYNAMIC DISSIMILARITY

As pointed out, the test model was not completely similar to the actual flying boat in that horizontal deceleration, variable lift, and structural flexibility were not represented in the tests.

The first of these is relatively unimportant, since the impact is of very short duration and no significant change in horizontal velocity could occur unless horizontal forces greatly exceeded vertical load (which is unlikely except from nosing under).

The lack of variable lift is a rather serious hindrance in any quantitative study of the flight path after impact. Probable bouncing off and trimming characteristics can be discussed in a qualitative way only. The problem of attitude for the return to the water after a previous impact is necessarily a function of air lift. For these actual cases has been substituted the arbitrary range of constant trim angle (which should be a reasonable approximation).

In a modern hull the wing flexure is probably the major factor in the structure which may affect the resultant hull accelerations. If model weight would permit, a dynamically similar wing could be mounted on the model; but it is thought that the effect upon the hull loads would be small in this case since the wing natural frequency is not far different from the effective impact frequency.

EFFECT OF MOMENT OF INERTIA AND CENTER-OF-GRAVITY POSITION ON IMPACT

Short tests were made with changes in inertia and center-of-gravity position of the model. No definite effect could be noticed upon the center-of-gravity acceleration; while the angular accelerations were too scattered definitely to establish a trend. There appeared to be a slight reduction in angular acceleration with doubled inertia, but not at all so much as had been expected. Evidently, the bow loads are substantially increased as the increased inertia maintains the bow penetration for a longer time.

CONCLUSIONS

Quantitative conclusions based upon these introductory rough-water dynamic model tests must necessarily be tempered by lack of full substantiation of the test procedure as indicative of full-scale performance. Nevertheless, definite trends have appeared and an approximate prediction of ship performance seems justified for the basic landing condition chosen.

1. The average peak acceleration at the center of gravity is mainly a function of wave height irrespective of trim (0° to 6°), center-of-gravity position, or moment of inertia.

2. The peak angular acceleration increases with increased wave height and length and tends to be higher at low trims.

3. The contact position along the wave is a very strong influence on center-of-gravity acclerations and is a major factor in angular acceleration and bow loads.

4. The JRM-1 at 165,000 pounds will operate satisfactorily in 3.5-foot waves with best landings obtained at 4° or 5° contact angle (base line).

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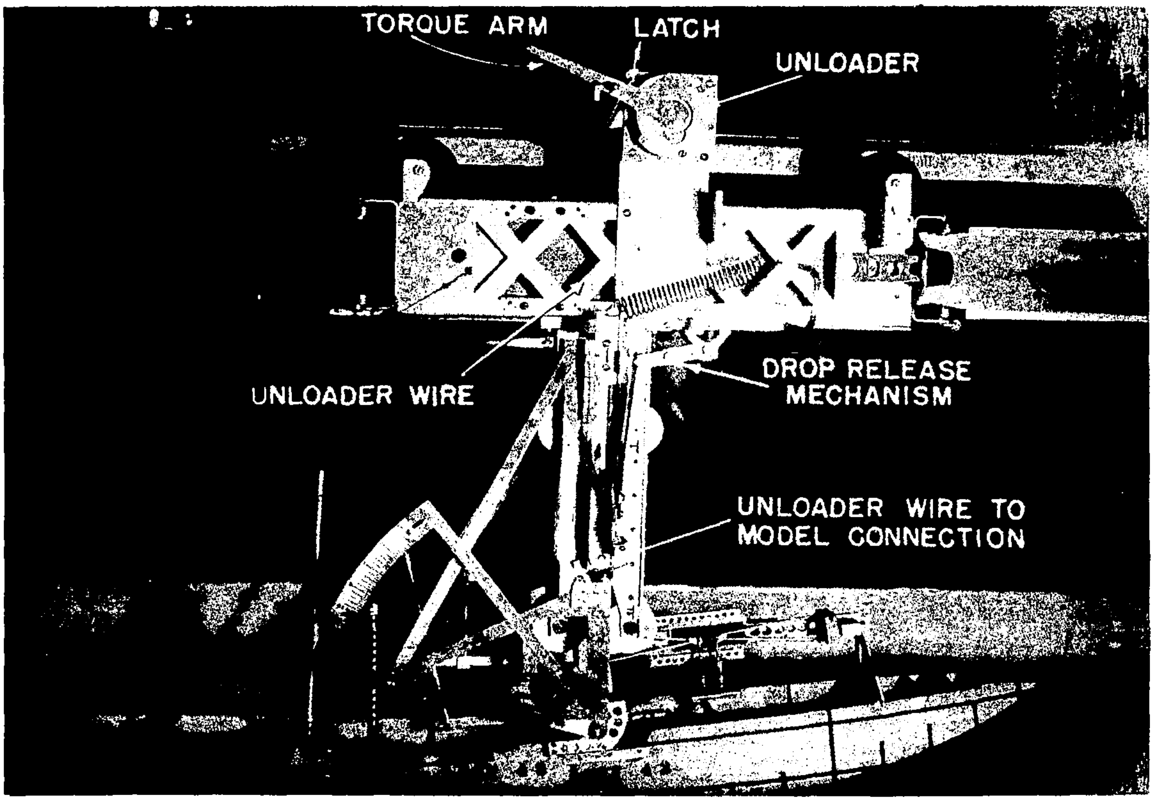
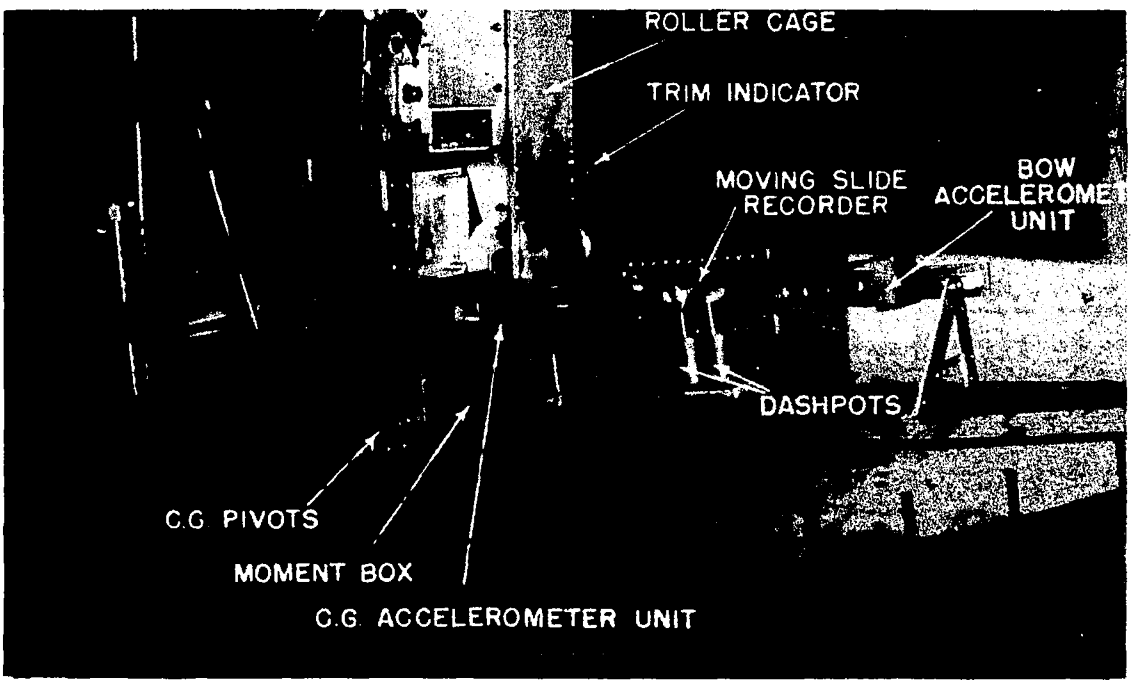
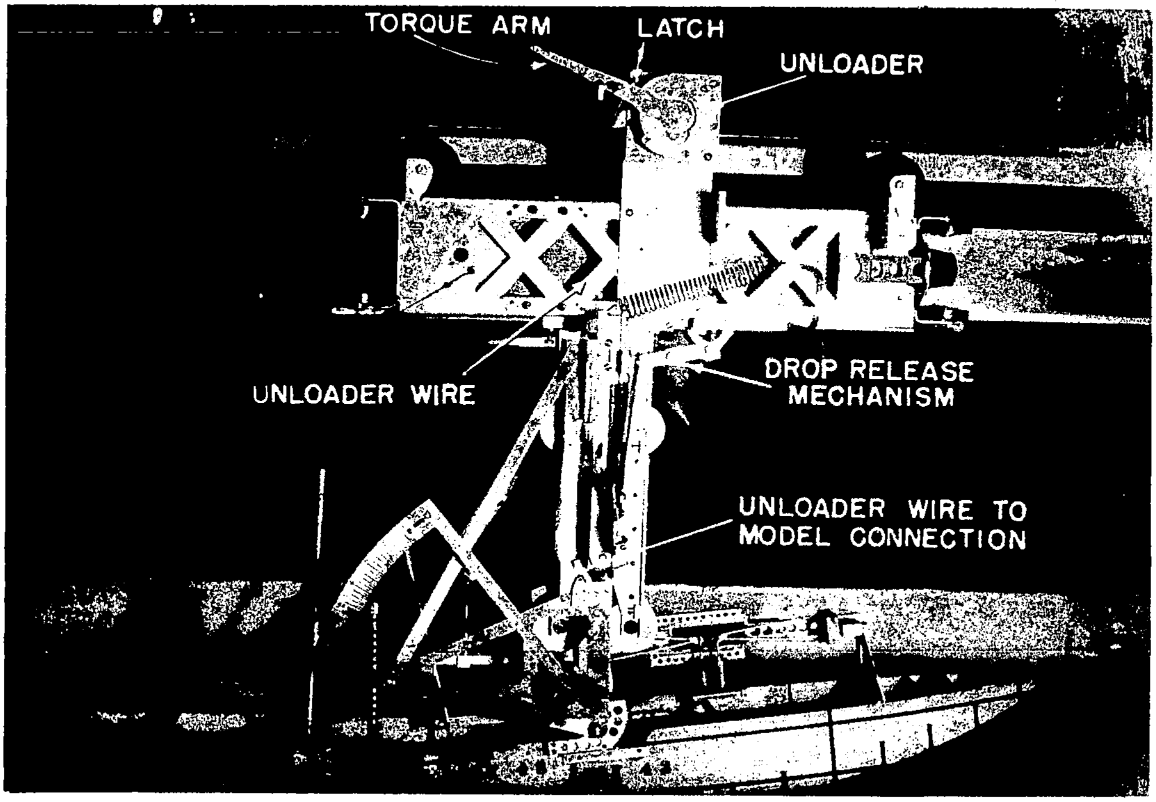
3. Hugli, W. C., Jr., and Drake, C. J.: Landing Impact Tests on a 1/30 Scale Model of the JRM-1. Exp. Towing Tank, Stevens Inst. Tech., 1945.



Apparatus setup for landing impact tests.



Detail view showing accelerometers.
Figure 1.



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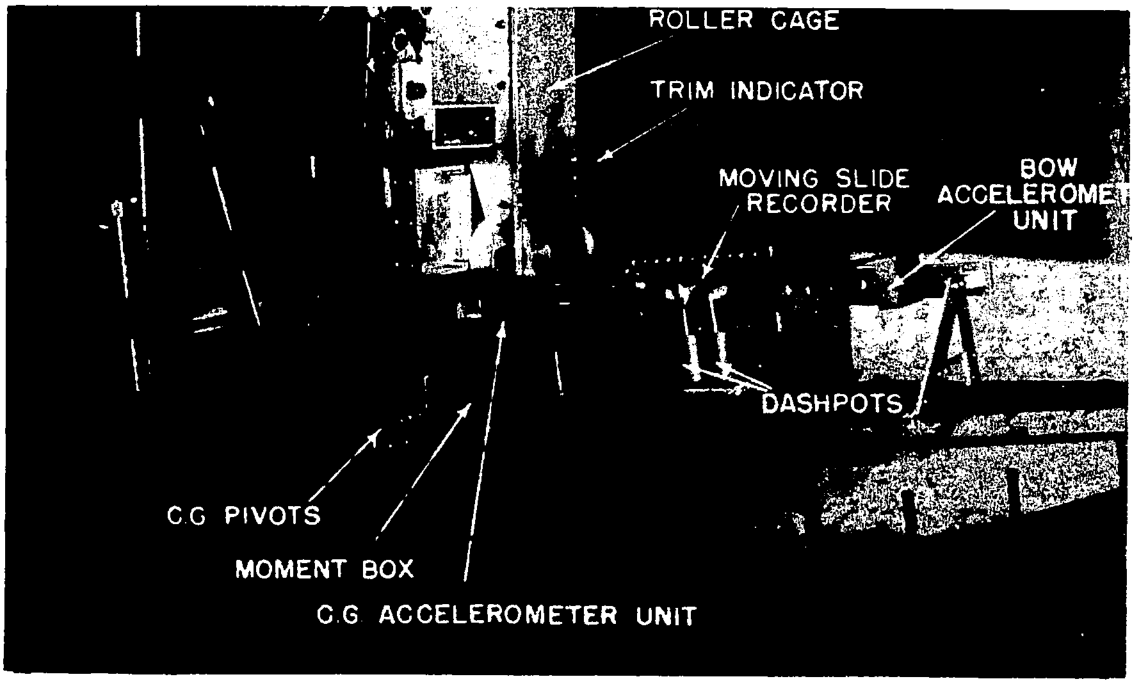

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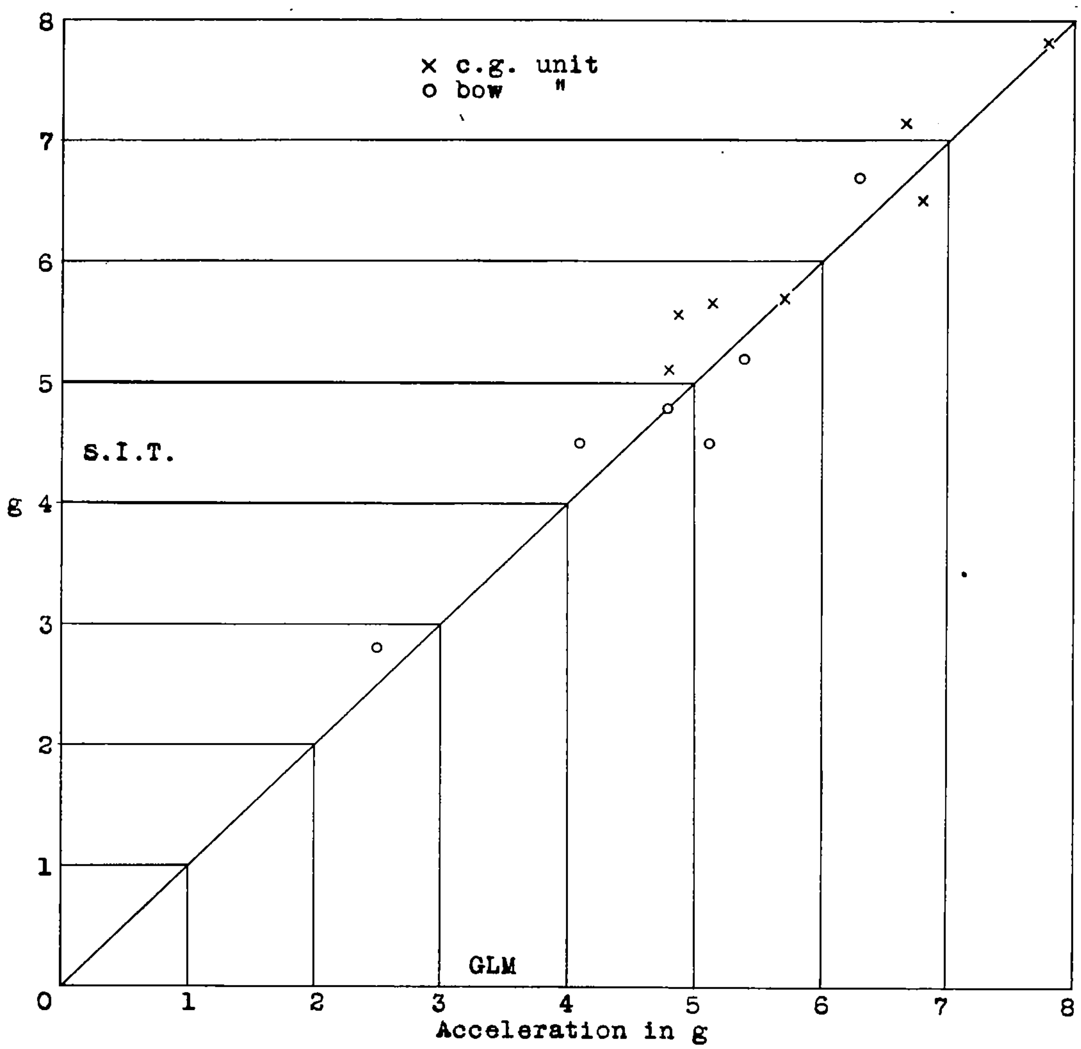

Figure 2.- Comparison of recorded accelerations, S.I.T. and GLM pick-up.

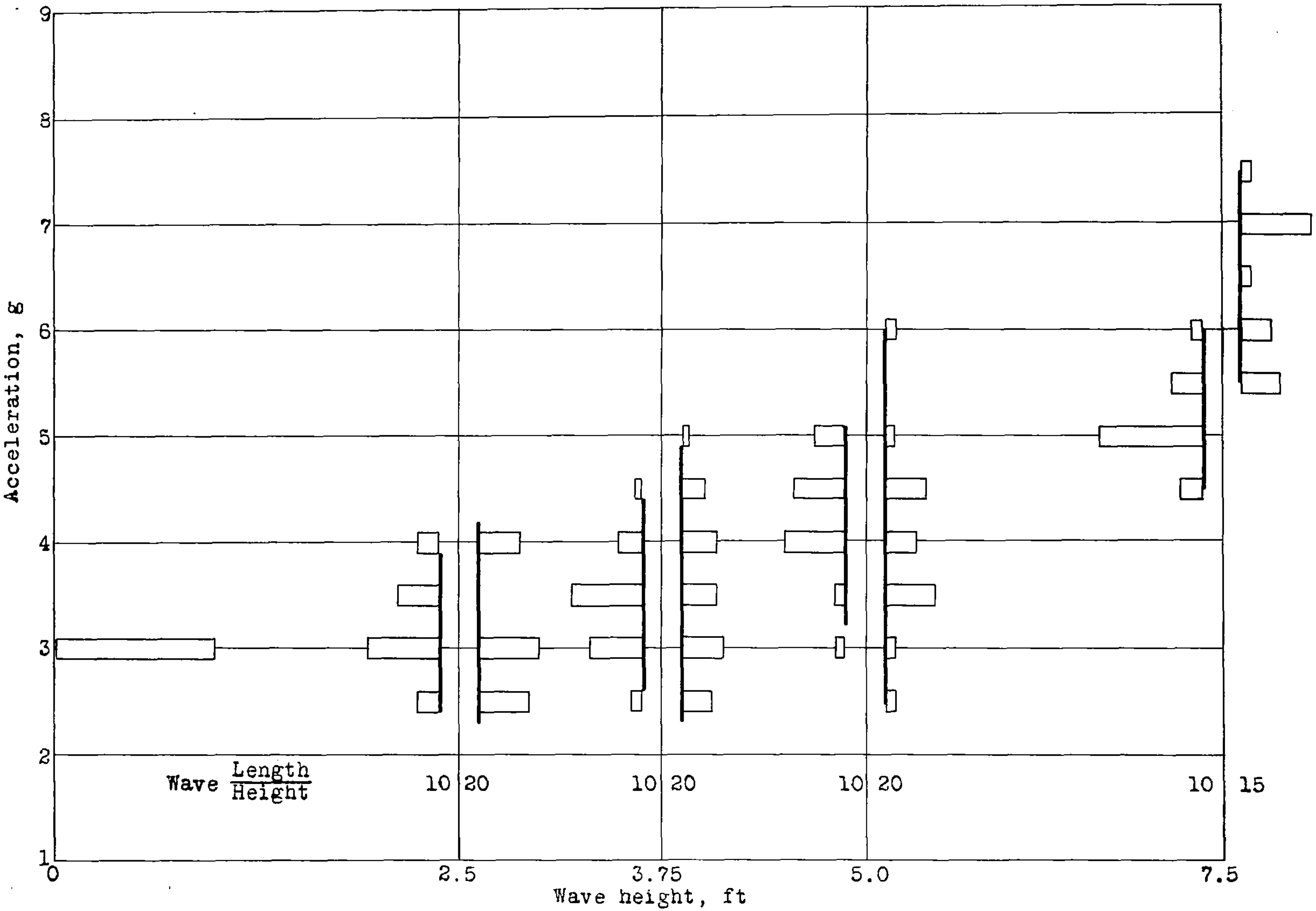

Figure 3.- Rough water impacts JRM-1, frequency of occurrence peak c.g. acceleration.

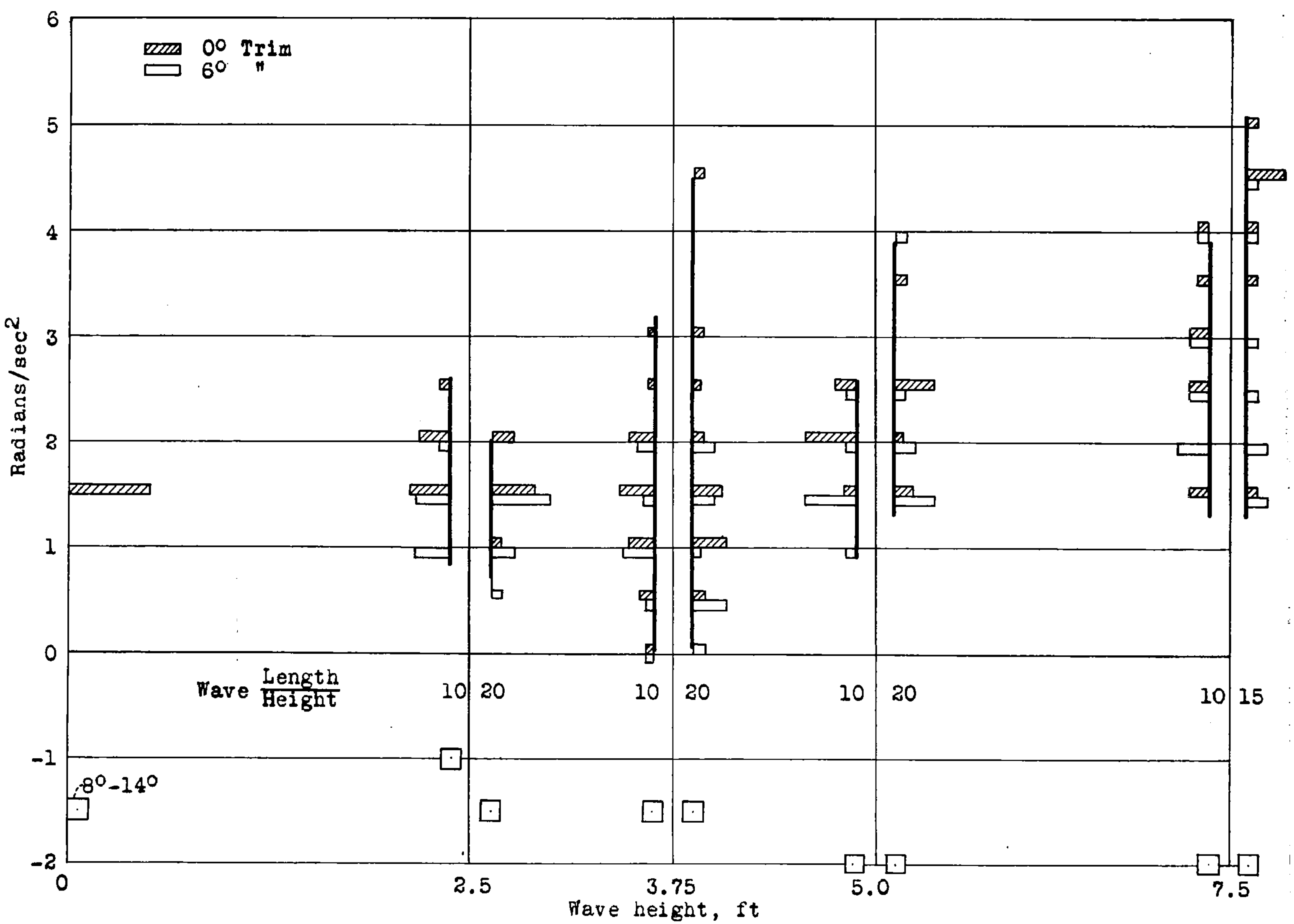

Figure 4.- Rough water impacts JRM-1, frequency of occurrence ∽ angular acceleration.

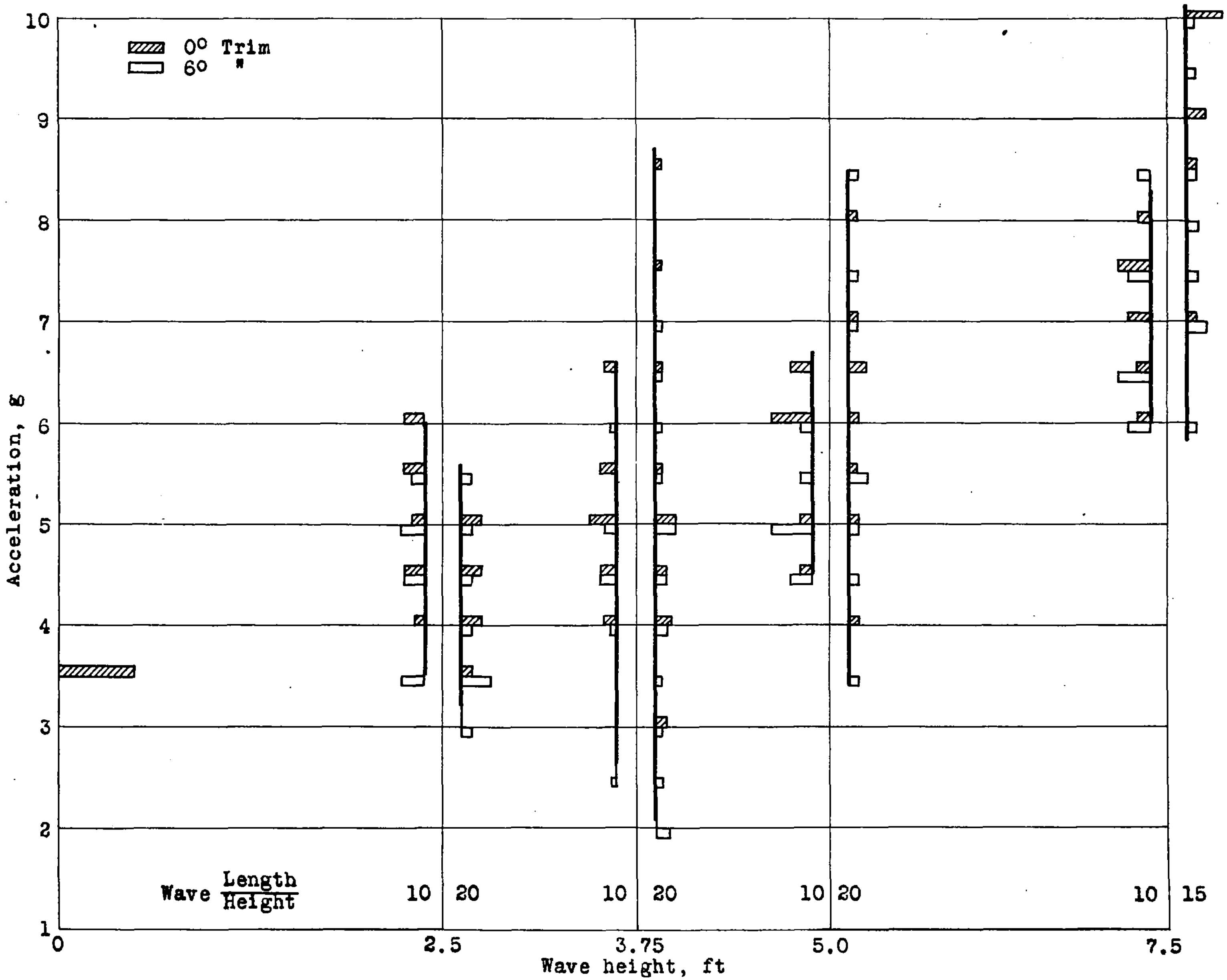

Figure 5.- Rough water impacts JRM-1, frequency of occurrence of peak bow acceleration.